

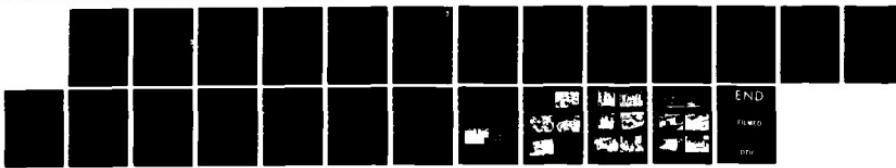
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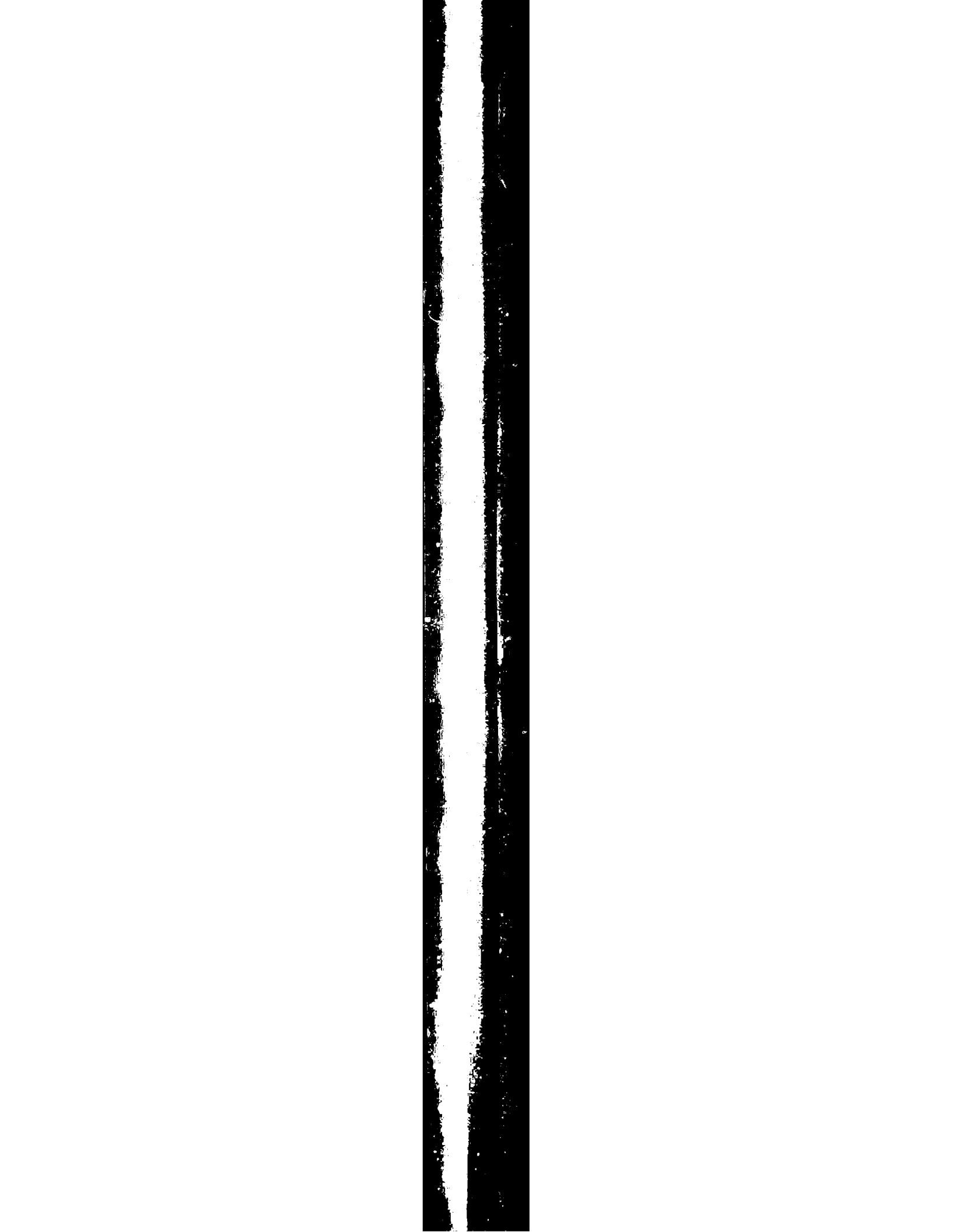
HIGH PRESSURE ENVIRONMENTAL CONDITIONING SYSTEMS AND
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BUFFALO DEPT OF PHYSIOLOGY H RANN ET AL. 15 NOV 84
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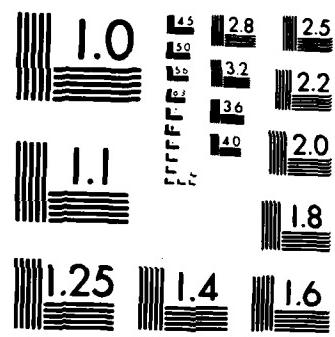
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Title: High Pressure Environmental Conditioning Systems and Chamber Rehabilitation

University at Buffalo, State University of New York, Department of Physiology, Schools of Medicine and Dentistry, Buffalo, NY

FINAL REPORT: ONR CONTRACT NOC014-76-C-0472

15 NOV 1984

(12)

This report covers the period from 110175 to 030183. During the last year (030182 to 022883) a No-cost Extension was in effect. Up to 123177 the Contract was named "High Pressure Physiology" and encompassed both physiological research projects and equipment development and acquisition. On 090177 the emphasis of this Contract was shifted to only involve the technical completion of the saturation diving facility and it was renamed "High Pressure Environmental Conditioning Systems and Chamber Rehabilitation." A physiological research program was subsequently begun under a new contract and title.* Consequently, physiological research publications under the Contract subject to the present report were only generated during the first 26 months of the grant period.

Principal investigators under the Contract were Dr. Hermann Rahn between 110175 and 053077 and Dr. Claes Lundgren between 070177 and 022883. CTE

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Physiological Research

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The physiological research performed under the Contract ranged from cellular function and membrane function to the performance of whole organisms under conditions relevant to the diver's situation.

A study of ionic currents in the voltage-clamped squid axon exposed to helium pressures of up to 204 atmospheres has been performed ~~150~~. It was shown that pressure slows the time course of both early and late ionic currents. Because the maximum conductances for sodium and potassium were not significantly affected by pressure it was concluded that the number of ionic channels which open during excitation does not change and that pressure affects the kinetics of channel opening and closings; that is the gating processes were primarily affected. These and other observations in the same study may contribute to an improved understanding of the pathophysiology of the so-called high pressure neurological syndrome which

"Effects of Static Lung Loads on Cardiorespiratory Function in Submerged Exercising Subjects at Depth;" NOC014-78-C-0205, starting date 010178.

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is a major obstacle to human diving at great depths.

One study (4) under the Contract addressed the effects of pressure per se on sodium transport and ATPase activity in human erythrocytes. The sodium efflux rate constant declined 40% over the range of 1-35 ATA and then more slowly from 35-150 ATA with only a small further reduction at pressures over 150 ATA. Na-K-ATPase activity in open erythrocytes ghosts increased with pressure in apparent conflict with the earlier mentioned decrease in Na-efflux from intact cells. It was suggested that this discrepancy was because the flux measurements were made in intact cells and the enzyme activity in open ghosts.

A major area of research initiated under this Contract and subsequently continued under the new contract identified in the footnote on page 1^{1/2}s related to the effects of hydrostatic pressure differences on the chest and lungs of a diver. Such pressure differences may be encountered by shifting body position underwater (Fig. 1). Similarly, different types of breathing gear may induce either a positive or negative static lung loads depending on the position of the device determining breathing gas pressures and therefore alveolar gas pressure, relative to the hydrostatic pressures on the diver's chest.

In order to allow such conditions to be created under controlled experimental circumstances in the hyperbaric chamber a special apparatus was developed and tested (9, 10). Positioning an experimental subject behind the so-called Lanphier-Morin barrier above the air-water interface (positive static load), at the interface (zero load) or below the interface (negative load) (Figs. 2, 3) while monitoring the subject's cardiorespiratory performance could be recorded during rest and exercise. The cardiorespiratory parameters can then be monitored in a diver/subject while at depth (Figs. 4, 5).

Cont'd Pg. 2

The experimental apparatus referred to above has been and is being employed in a series of studies, the first one of which was published under this Contract (6, 8, 11). In this study, the respiratory performance of subjects exposed to static lung loads ranging from -30 to +30 cm H₂O was



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studied. The subjects performed graded exercise (up to maximal) in the prone position on an underwater bicycle ergometer while breathing air at pressures corresponding to a maximum depth of 160 feet.

While a moderate degree of hypercapnea was seen at depth, especially during heavy exercise, static lung loading did not have any systematic effect on gas exchange parameters including end-tidal gas concentrations, oxygen uptake and carbon dioxide elimination. By contrast, there was a marked influence on dyspnea (shortness of breath) scores by static lung loading, dyspnea being considerably more severe during negative static lung loading while positive static loading at about 10 cm H₂O was connected with the least shortness of breath.

A moderate positive static load allowed the subjects to complete maximal exercise bouts of 5 min at 160 feet of depth which was frequently impossible with negative static lung loads. These findings have implications for the design of breathing gear for divers and for the tactics of how to perform underwater work. In addition, the results help to phrase the theoretically interesting question: is the exercise dyspnea at depth due to respiratory muscle fatigue? The observation that dyspnea was inspiratory in nature and alleviated by positive static lung loads (acting to insufflate the lungs) seem to support such a notion.

Several studies addressed pulmonary gas exchange related to gas-phase diffusivity and gas flow resistance.

In the dense atmosphere of a hyperbaric environment, diffusive mixing of gas molecules is curtailed; for example, rate of oxygen diffusion in air at 10 ATA is reduced to one-tenth of normal. Studies in divers showed that low diffusivity decreased the effectiveness of gas exchange, but that the effect was not strong (7, 17, 19, 21, 22, 23, 24, 26) a ten-fold decrease of diffusivity caused only a 10 or 20% decrease of exchange effectiveness (27).

The changes of the mechanics of the pulmonary system brought about by dense gas are expected to be most serious during exercise. It was found

that exercising divers responded to the high flow-resistance in dry hyperbaric environments by increasing the lung volume and by altering the distribution of ventilation (12, 13, 16, 18, 25).

Several projects provided necessary background to the hyperbaric exercise and diffusivity studies. The interactions of O₂ and CO₂ with the inert gases in the lung were analyzed (14, 15), and a method was developed which allowed correcting for unavoidable artifacts introduced by the measuring instruments (1), and the authors made sure that they could account for all of the gases breathed in, breathed out and remaining in the lung (20), and studied time (as opposed to diffusivity) as a factor in gas mixing (2, 3).

High Pressure Environmental Conditioning Systems and Chamber Rehabilitation were also Studied.

A pressure chamber with subsystems for experimental compressed air diving was procured, installed and taken into use for research in the period between 1971 and 1975. This chamber system was built to allow experiments at up to 170 atmospheres corresponding to a water depth of 5700 feet (Figs. 6, 7).

The use of the chamber facility for experimentation with human subjects at depths greater than those reachable with air breathing required major additions to the chamber including a high pressure helium storage, a "life support" system for purification of chamber gas, sanitary systems, temperature control equipment, fire suppressant system, new communication systems and other ancillary equipment. In addition, some major components of the original air diving system (compressors, valves and plumbing) which were installed when the hyperbaric facility was first built were Navy surplus having seen many years of service before installation here and have required replacement during the duration of this Contract.

The work to complete the chamber complex as a modern combination altitude-deep saturation diving hyperbaric facility have been ongoing (interspersed with research) during the Contract period as detailed in the

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following.

November - December 1975

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Further improvements were made on the 170 ATA facility. A set of Carty lights (through-the-chamber hull lighting) were installed. A four cylinder pump intended to provide gas circulation in the "life support" plumbing loop and filters was designed by J.M. Carty Associates, built, and assembled for testing in our laboratory. The results were less than expected due to overheating and leakage of the piston seals. The project was shelved to await progress reports from the Defense and Civil Institute of Environmental Medicine, Downsview, Ontario who was testing the same system at the time. (A better type of pump was later conceived, procured, and installed in our facility as detailed below.)

1976

At this time, the main thrust of the research program involved experiments on Static Lung Loading in the wet compartment of the 170 ATA chamber while work on chamber improvements were continued. To support air dives to 190 ft, many changes were made to the equipment involved. The bag-in-box breathing system inside the chamber (Fig. 8) was modified to include a humidified fresh air supply. For monitoring of expired gas composition breath-by-breath, a 1 ATA system was devised to transport the gas to the Perkin-Elmer mass spectrometer. To insure that the dive depth be maintained accurately, a highly sensitive manometer of a new design was conceived, built, and installed inside the chamber where the outside operator could view it to correct depth changes as small as one cm of H₂O at total pressures of more than 6.7 ATA (190 feet). This device is very important for precise measurements of respiratory gas volumes which are sensitive to small pressure fluctuations in the chamber. A new system for treatment of the chamber "wet pot" water was constructed. This consisted of a filling, heating, and recirculation loop in the wet compartment of the chamber that also included a filter. Because a Collins bicycle ergometer was being used underwater extensively a simple means for calibrating the submerged equipment was required (10). It used a suspended motor, belt,

pulleys, and a force gauge.

A small 400 ATA chamber (Fig. 9) for in vitro experimentation was constructed this year. It has a sliding door at either end for easy access. Perpendicular to the bore in the center are two plexiglass viewports. All of the necessary valves, lights and electric leads were installed and the system has since been used to study single cell and tissues at pressure. To compliment the chamber, an electric drive micro-manipulator with X, Y, Z, Z' movement was designed and constructed in-house to accommodate these experiments. The 200 ATA chamber used for the squid axon study was refurbished completely this year. It had been subjected to long exposures by salt water and was in need of an overhaul.

1977

1977 was devoted primarily to initiating and continuing projects designed to complete the 170 ATA chamber facility for saturation diving. However, the chamber continued to be used extensively for air diving to 300 ft.

In connection with the research on subjects exercising underwater in the chamber it was thought useful to directly measure the drag component of a diver's legs moving through the water while exercising on an ergometer. For this purpose a set of mechanical legs were constructed. At first, they were made of wood, weighted and jointed, to test the feasibility of such a study. Next, a set of fiberglass legs were manufactured. However, the project was technically complicated and was terminated when we conceived of a simpler, indirect physiological method of estimating the hydrodynamic work of leg movements underwater.

Two small volume high pressure chambers were constructed this year. One, a 200 ATA chamber, was designed to study red blood cells at pressure. The other, a 400 ATA chamber, was put in service to study tissue homogenates. Both chambers plus the existing larger 400 ATA chambers are supplied with gas pressure from the compressor house and tank farm.

1978

This year the laboratory space was being consolidated and expanded with funds from the School of Medicine. The three rooms in Sherman Hall containing a 7.8 ATA high pressure chamber and altitude chambers were vacated and the pressure chamber was relocated in a larger area next to the existing 170 ATA facility. The Sherman Hall compressor equipment was moved to the compressor house (Fig. 10). In anticipation of modifying the 170 ATA chamber for altitude simulation the existing old altitude chamber and a smaller outdated RIX air compressor were deemed obsolete, declared excess equipment, and transferred to the University of Wisconsin. The consolidation and expansion of space greatly improved the effectiveness of the laboratory.

These changes in space utilization enforced a break in the ongoing Static Lung Loading research program, and during this period of time refurbishing of the 170 ATA chamber's interior was performed. Most of the renovation was accomplished by the laboratory technicians with help from the departmental shops. The last two years of frequent wet diving had taken its toll on the chamber's interior finish. The entire interior was disassembled, the finish sandblasted to bare metal, and a new multi-coat finish reapplied. Following a cure period, the chamber was again reassembled using new seals and refurbished fittings. The system was tested and once more ready for air diving simulation.

1979

About 90% of the proposed Environmental Control Loop which would allow the 170 ATA chamber facility to function as a saturation system was installed and leak tested this year. The loop consists of four tower type pressure vessels which hold canisters loaded with absorbents and dessicants to remove unwanted CO₂, water vapor, and other contaminants from the chamber atmosphere (Fig. 11). The towers were connected to the two compartments of the chamber by 2 inch stainless steel piping. The gas is controlled by large ball valves and moved through the loop by magnetically coupled blowers. Eight canisters allow varying combinations of

contaminant-removing materials to be inserted in the environmental control loop vessels without interrupting pressure experiments.

The problem of transferring sufficient power through the 170 ATA pressure hull to operate the large blowers necessary to move chamber gas through the environmental control loop, was substantial. Clearly, sealing around moving shafts would be extremely difficult. The problem was solved when the Defense and Civilian Institute for Environmental Medicine offered the use (free of charge) of their technology for magnetic coupling between motor and fan. This technology had been developed for the facility in Toronto which is similar to this facility. In exchange, the Defense and Civilian Institute for Environmental Medicine has benefited from the technology of our transfer locks, doors, plexiglass ports, and wet-dry barrier system. It is expected that this exchange will continue to mutually benefit both facilities.

In order to be able to properly calibrate the Collins bicycle ergometer, the laboratory designed and built an improved calibration machine this year. As the Physiology department has a number of Collins ergometers, the machine has become a useful tool.

This year, a rebuilt machine lathe was installed in the departmental machine shop. It was secured through the Defense and Industrial Plant Equipment Center and only the cost of refurbishing and transportation was paid by the Contract resulting in an important enhancement in the shop capacity at a very modest costs.

1980

Work on the Environmental Control Loop for the 170 ATA chamber facility was continued this year. An electric lift that rides on a trolley was installed for handling the large heavy canisters and lids of the pressure vessels (Fig. 12). A vibrating stand for packing the absorbent canisters was designed and assembled in-house. This vibrator and an oven to regenerate silica gel by heating, were both installed and are ready for service.

Sixteen new 20 ft³, 6000 PSI gas storage tanks were added to the pad area (Fig. 13). The bottles which are rack mounted for easy manifolding added approximately 128,000 ft³ of inert gas storage to the facility.

Outside surface heaters on the chamber have been installed. They consist of 30 flexible resistance pad heaters and 10 straight chromalux resistance strip heaters. Sensors on the chamber surface feed proportional controllers to maintain the desired temperature.

The 7.8 ATA deck decompression chamber was completely refurbished (Fig. 14). This project was spread over a period of two years so as to not delay ongoing research. The chamber was stripped to the shell and repainted inside and out. New control valves and piping were installed. New lighting (Canty lights), electrical wiring and communications were added. The inside gas breathing system was refurbished. To insure that laboratory space could be utilized fully, the chamber was equipped with an air cushion system designed and built in-house. It allows one person to easily move the one-ton chamber.

A document insuring the pedigree of the 170 ATA chamber and supporting equipment was prepared for submission to the Commander, Naval Facilities Engineering Counsel (OHB). This document was required for the facility's certification for Naval man rating. This process had been ongoing and was now close to completion.

There were three other additions of equipment to the laboratory and shop this year which are essential for equipment construction and in-house repairs. The machine shop took delivery of another metal lathe supplied by the Defense and Industrial Plant Equipment Center. A minimal cost for refurbishing and shipping was the only expense to the Contract. Also two welding machines were purchased. One is a Miller combination electrode and TIG welder. The other is a Jones stud welding machine. The latter machine is particularly useful for attaching equipment to the inside and outside walls of the chamber.

1981

This year less work was done on the chamber facility than during preceding years due to a substantial cut in funding.

A set of plans for completion of the facility for saturation work was finalized. Work continued on the environmental control loop. Delivery was taken on two 5.3 ft³ 170 ATA spherical pressure vessels. One sphere is to be used as a waste container for the sanitary system and the other will contain fresh water for inside chamber use. Most of the valving for these two systems had been purchased earlier under this Contract. The environmental control loop valves, being made of carbon steel (for cost reasons) needed rust protection against moisture in the chamber gas. The valve parts were therefore sandblasted and chrome plated by a process called "Metalife."

The material for external heat insulation of the chamber was received. (Installation of this material is deferred until a final rearrangement of the piping system is completed).

As the need for another hypobaric or altitude chamber became apparent (having given the University of Wisconsin the original altitude chamber), plans were made to extend the capability of the 170 ATA chamber to altitude simulation. New outside doors were manufactured and all chamber penetrations were converted to operate both with vacuum and over-pressure. At the time of writing only a small amount of work remains to install control valves and gauges.

The Defense and Industrial Plant Equipment Center again contributed a much needed milling machine. The refurbished machine was added to the departmental shop and is now used daily for prototype and repair work.

1982

This year was the last funded year of this Contract with a closing date of February 1983.

The major item completed this year was a new gas distribution panel for the 6000 PSI inert gas storage system. The panel consists of stainless steel tubing and valves mounted to the compressor house wall (Fig. 15). Stainless steel tubing was employed to connect the gas storage tubes with this panel.

Following a visit by our personnel to the Experimental Diving Unit at the Naval Coastal System Laboratory in Panama City, FL, the laboratory was loaned a number of pieces of equipment. One piece was a much needed Corblin diaphragm compressor. Another item was a back-up 3000 PSI Type 30 Ingersoll-Rand air compressor. Some other excess equipment was also made available. Three 20 ft, 3000 PSI gas storage tubes, one stainless steel low pressure water tank for fire suppression, plus various valves and control equipment were among the useful items received.

1983 to Present

This section of the report gives some information of activities within the scope of the Contract which have been continued after its expiration date. This is to underscore the fact that not only are the investments in this facility in cost and work made useful in an ongoing and very active experimental schedule* but the work towards completing this facility as a combined altitude/high pressure saturation dive complex is systematically pursued as funding from various sources can be secured. The facility is very near completion, and will, when finished, be unique of any chamber facility for a couple of reasons: it covers the widest pressure range in the free world: 0.1 - 170 atmospheres corresponding to 50,000 feet of altitude and 5700 feet of depth. Most important: the chamber facility is cheap to operate because of moderate size and efficiency and simplicity of layout; it requires relatively small volumes of expensive gases for deep pressurizations; it can be run in the saturation mode with an outside crew

*In the period September 1983 - September 1984 the laboratory had 112 days of experimental dives in the chamber totalling 371 man-dives and 646 man-dive hours.

of only two persons (plus one who may sleep but should be available on-site) during night and three persons during the day.

One result of the continued improvement program is that the chamber complex was awarded a U.S. Navy System Certification of Material and Procedural Adequacy in December 1983. The certificate was issued for saturation diving to 1000 FSW. It is expected that, with the completion of more of the planned improvements, this certification can be extended to the full 170 ATA chamber capability.

The major improvements that are being worked on are mentioned in the following. A set of heat exchangers in the chamber for controlling temperature for both chamber compartments are being tested. However, these exchangers are dimensional for maintaining temperature at stable chamber pressure and they are not adequate for rapid pressure excursions. Therefore a set of external heat exchangers for insertion in the environmental control loop are also planned.

Plans for living accommodations have been designed and are partially completed. Some of the floor decking and seating arrangements are finished. The sanitary and potable water systems are planned but need some piping and valves for installation and connection to the chamber. A schematic for an outside-controlled fire suppression system is complete and the pressure vessel for water is in-house. As soon as the funds can be found for the valving, piping and salary costs, the system will be installed. A new stainless steel air distribution panel is planned for the chamber room. It will replace the original steel pipe.

The facility is benefitting from an ongoing building program funded by the University. A new addition to Sherman Annex and connecting with Sherman Hall will result in an expansion of the laboratory by approximately 3000 ft² (Figs. 16, 17, 18). The plans include a new compressor house with a maintenance room and tank farm. The new laboratory addition will include three lab areas, a gas mixing room and increased gas cylinder storage. Since the existing compressor house has to be razed to clear the area for the new laboratory addition, the university will replace all existing steel

pipe with stainless steel tubing. The steel pipe manifold compressor house will also be changed to stainless steel tube at

Early in 1983, the prime air compressor (Ingersoll-Rand Type 6R80) had been relied on since 1970 ceased to function. For its repair of large portable Ingersoll-Rand type 6R80 air compressors located as excess equipment at the Naval Weapons Station, China Lake, California. Since the laboratory is a Department of Defense contract facility, the machines were shipped free of charge to this facility. Since the machine has been refurbished as a portable unit powered by the Continental gas engine (Fig. 19). The second machine is being converted from an electrically driven stationary air compressor and will be installed as a prime unit in the new compressor house that is being built. The laboratory now has two reliable high pressure air compressors valued at \$12,000 each. The laboratory's cost was \$19,000 to refurbish and modify both compressors.

Recently two more major pieces of equipment were added to the laboratory facility. One is a Linde metal inert gas welder to facilitate the fabrication of new stainless steel cabinets and decks for the chemical storage tanks. The other piece of equipment is a Haskell 4500 PSI oxygen transfer pump (Fig. 20). This pump will allow oxygen mixes to be transferred to high pressure storage for emergency use.

The School of Medicine's Class of 1956 has bequeathed a sum of money to the Department of Physiology for purchasing a more sophisticated gas filtering system for the high pressure compressors. The new system consists of two coalescing canisters, vapor trapping canisters and a carbon monoxide detector. The canisters have been installed and are now being tested.

Buffalo, New York

Hermann Rahn, Ph.D.

Distinguished Professor of Physiology

14 November 1984

Claes Lundgren

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Corning, New York
- 170 ATA Chamber & Environmental Control Loop Design and Inside Heat Exchangers
 - Through-the-Hull Chamber Lighting
 - 400 ATA Chamber
 - Work Calibrator Bicycle Ergometer
 - MGA 1100 Mass Spectrometer
 - Water Cooled Air Compressor
 - Magnetically Coupled Blowers
 - TIG-Electrode Welding Machine
 - Stud Welding Machine
 - Chrome Corrosion Roventative Finish
 - Burton Corblin Diaphragm Compressor
 - Type 40 Air Compressor
 - Type 30 Air Compressor
 - Type 6R80 Air Compressor

Linde, Union-Carbide Corp., Florence, South Carolina	- MIG Welder
Haskell, Inc., Burbank, California	- 6000 PSI Oxygen Transfer Pump
Balston, Inc., Lexington, Massachusetts	- Coalescing Air Filter
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	- Carbon Monoxide Monitor

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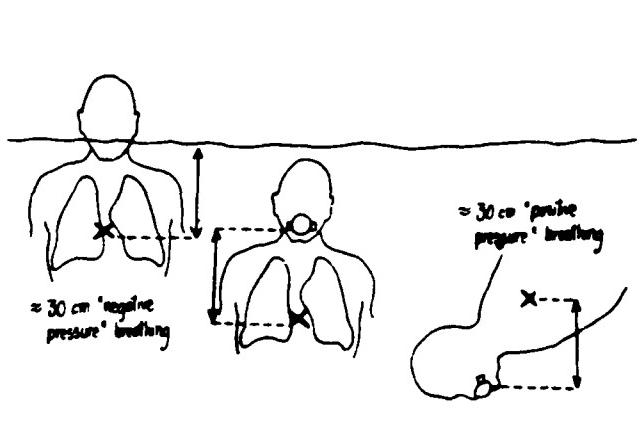


FIG. 1 Negative or positive pressure breathing (about 30 cm H₂O) resulting from unequal lung gas pressure and water pressure on the chest (pressure centroid represented by X).

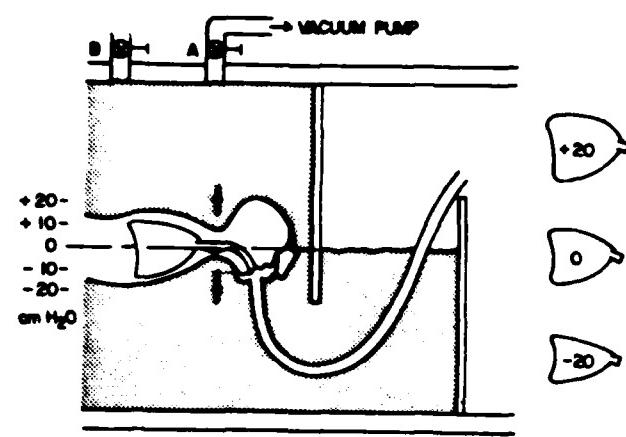


FIG. 2 Schematic representation of subject positioned behind Lanphier-Morin barrier above interface (positive static lung load; large lung volume), at interface (no load, normal lung volume) and below interface (negative load, small lung volume).

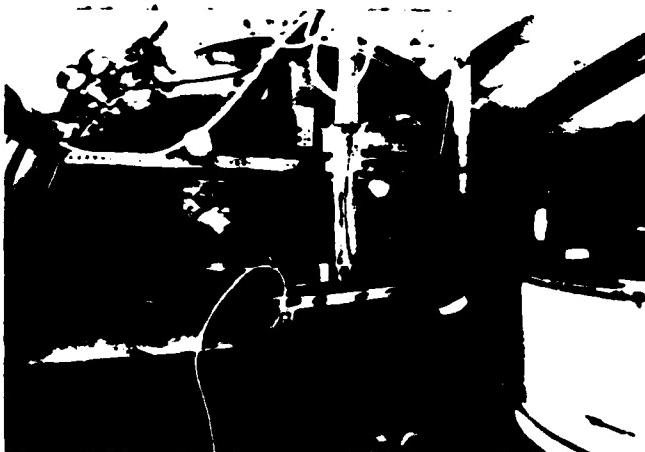


FIG. 3. 0.1-170 ATA Chamber Wet-Dry Barrier System Showing Immersed Subject.

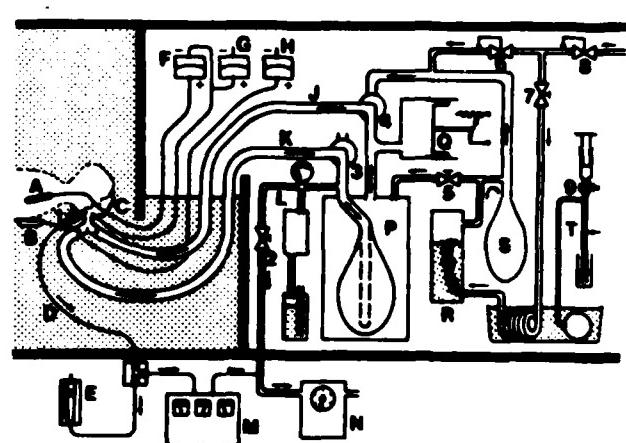


FIG. 4. Schematic of Bag-In-Box System for monitoring of respiration of submerged Subject at Depth.

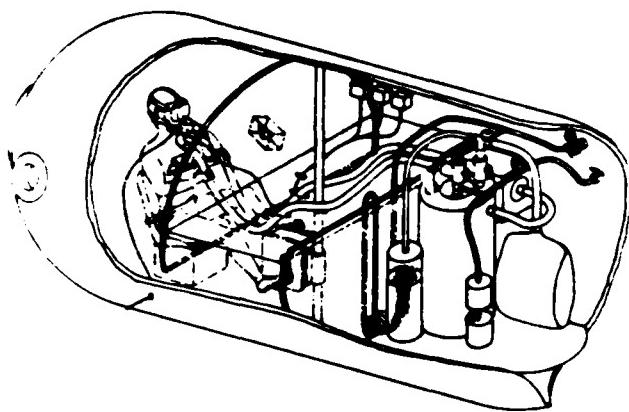


FIG. 5. Schematic of Upright Immersed Subject Pedalling Waterproofed Ergometer while Connected to Bag-In-Box Gas Collection System.

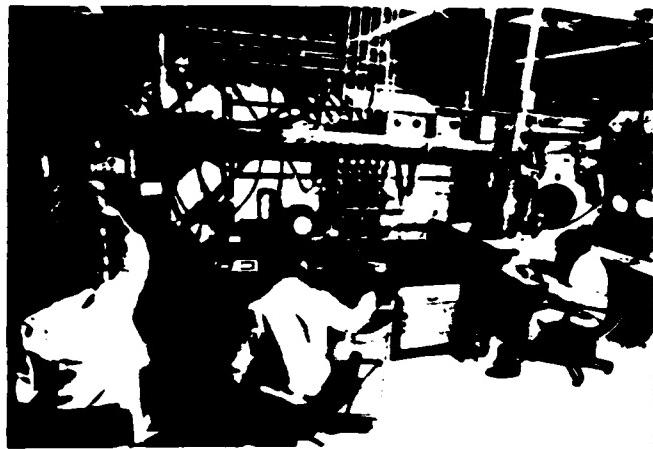


FIG. 6. 0.1-170 ATA Hypo-Hyperbaric Chamber with Grass 7D Polygraph and Perkin-Elmer MGA 1100 Mass Spectrometer.

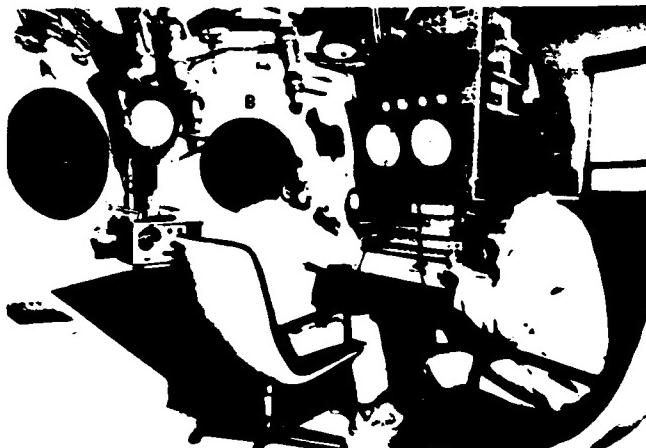


FIG. 7. Console of 0.1-170 ATA Chamber Showing Controls and Communications.



FIG. 8. Bag-In-Box Gas Collection System with Low Resistance Hoses.

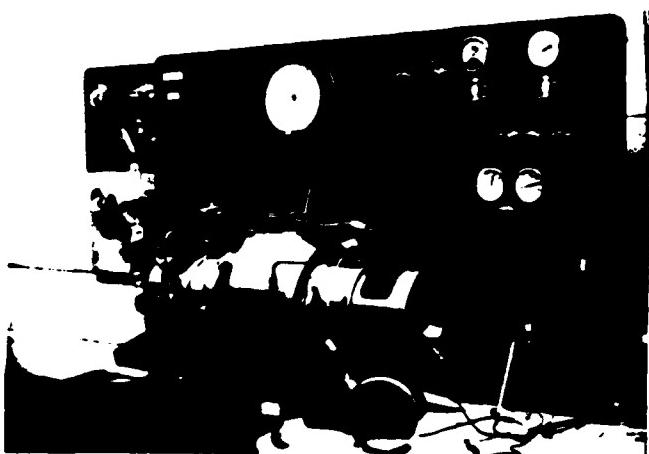


FIG. 9. 400 ATA In-Vitro Experimentation Chamber.



FIG. 10. Stationary Electric Driven 3000 PSI, 70 SCFM Air Compressor.

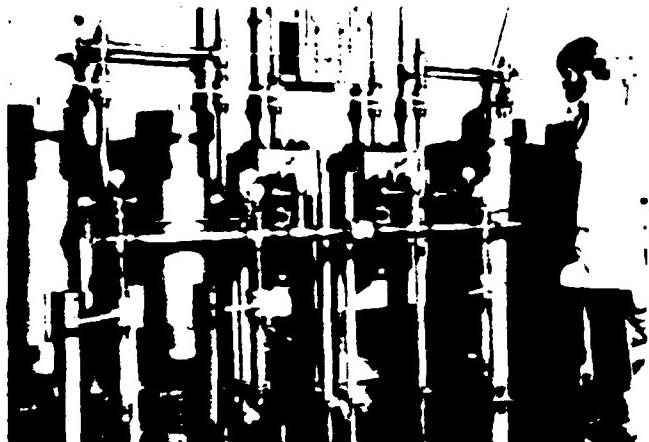


FIG. 11. 0.1-170 ATA Life Support Loop Cannister Pressure Vessels and Gas Transport Blowers.

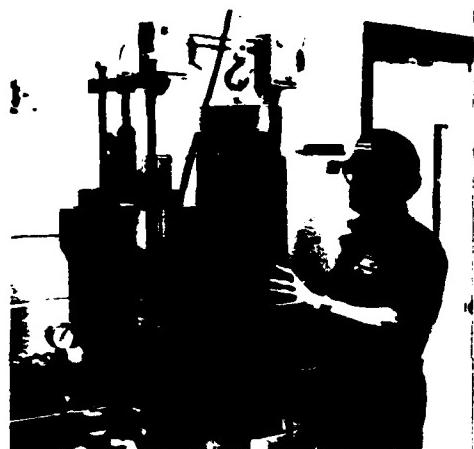


FIG. 12. Lift Hung Under Trolley Used or Hoisting Filter Cannister in "Life Support Loop."

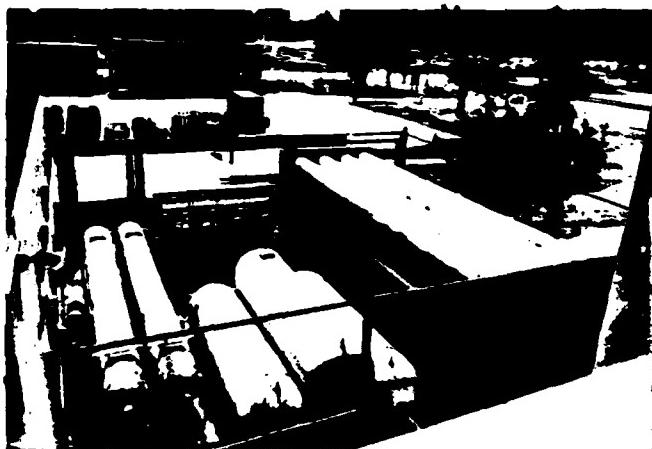


FIG. 13. Gas Storage Area Showing Two Sets of 3000 PSI Air Storage Flasks (Left) and Racked 6000 PSI Inert Gas Storage Cylinders (Right).

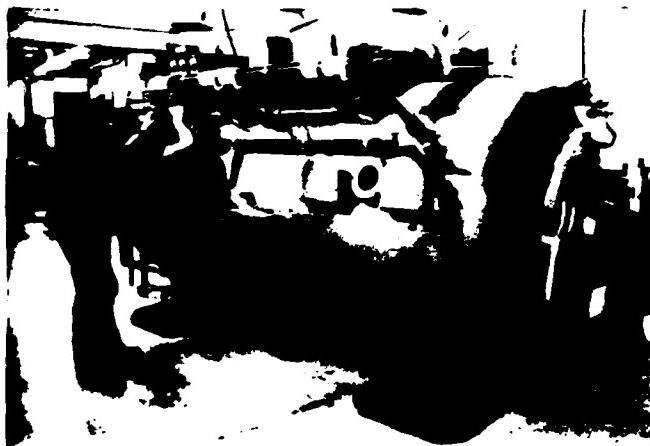


FIG. 14. Refurbished 7.8 ATA Decompression Chamber Mounted on Air Pads.

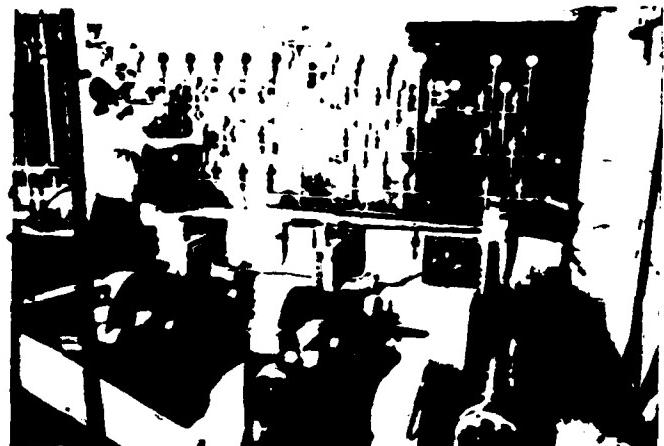


FIG. 15. 6000 PSI Hofer Diaphragm Gas Transfer Pumps and Gas Storage Distribution Panel.

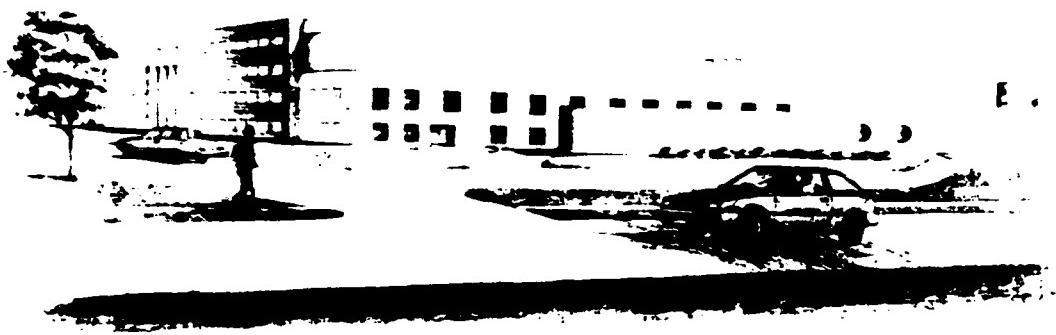


FIG. 16. Artist's Rendering of New Compressor House and Gas Storage Area Now Under Construction to be Located in Front of Expanded Sherman Annex.



FIG. 17. View of Sherman Annex Housing the Hyperbaric Facility Plus Compressor House and Gas Storage Pad.



FIG. 18. Compressor House and Gas Storage Areas as Shown in FIG. 16 is under Construction in October 1984.

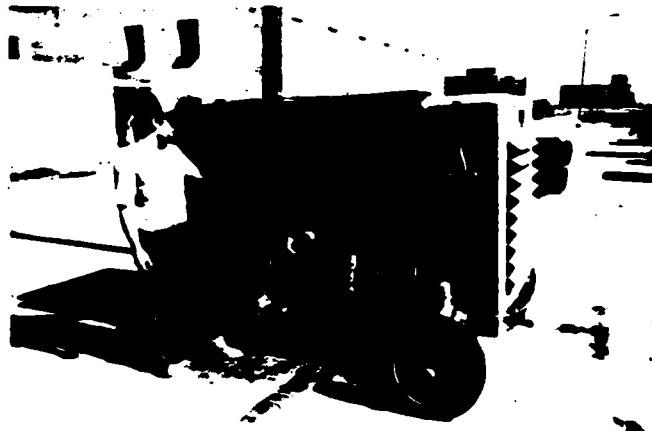


FIG. 19. Portable Gasoline Engine Driven, 6000 PSI, 80 SCFM Air and Nitrogen Compressor.

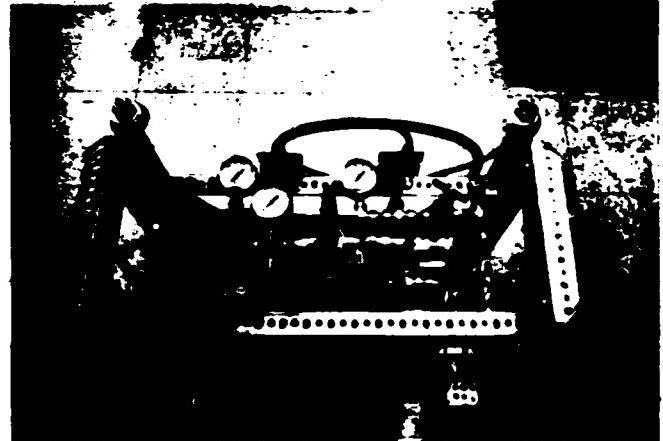


FIG. 20. Haskell 6000 PSI Air-Driven Oxygen Booster Pump.

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